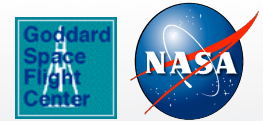




Time-Resolved Optical & Thermal Analyses of High-Power Laser Diode Arrays



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Outline



Introduction

“Standard” Performance Monitoring

Time Resolved Monitoring

Temporally Resolved and Spectral Resolved Laser Diode Arrays

Temporally Resolved Thermography of Laser Diode Arrays

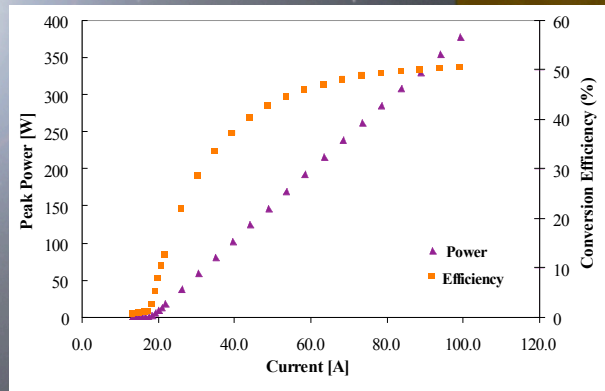
Thermal Model

Summary - Conclusions

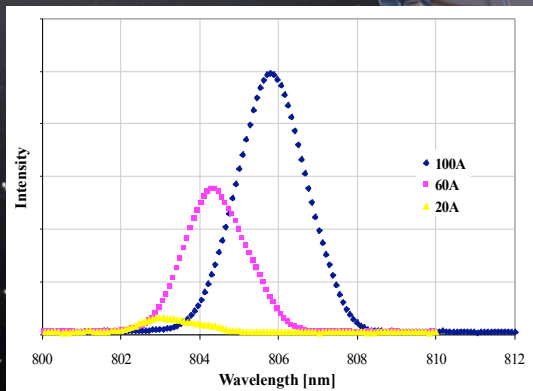
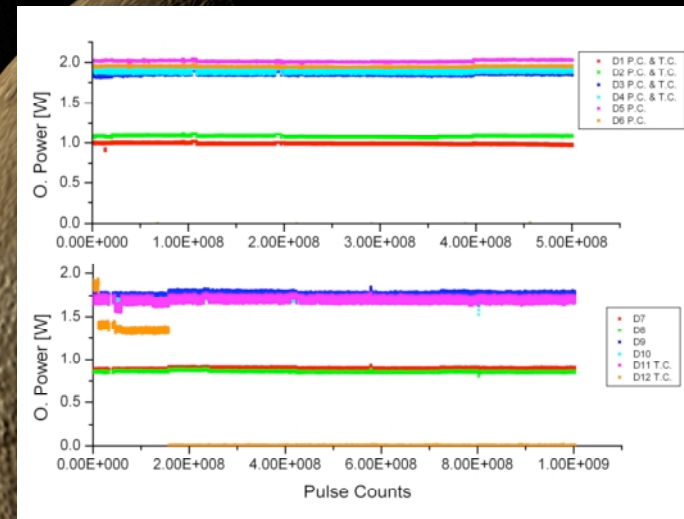
(TSR)- temporally spectrally resolved
(LDAs) - Laser Diode Arrays

“Standard” Performance Monitoring

Diode stack PI & Efficiency curves

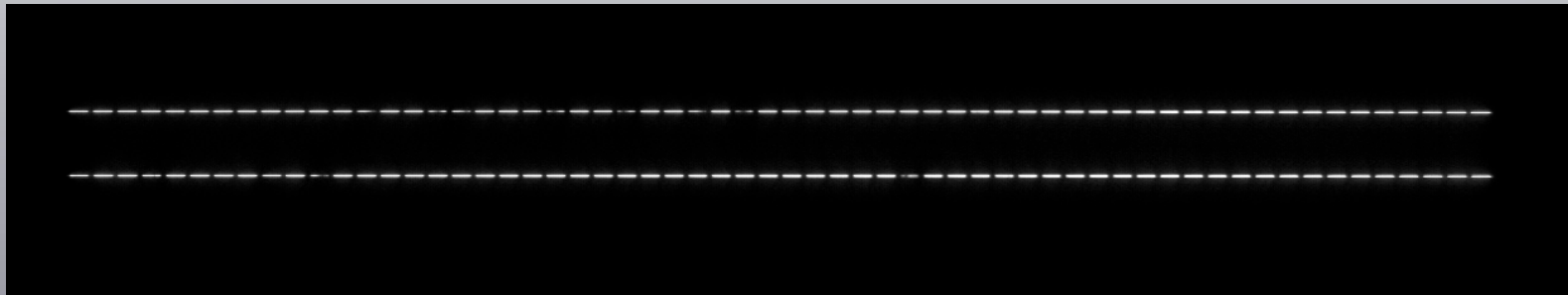
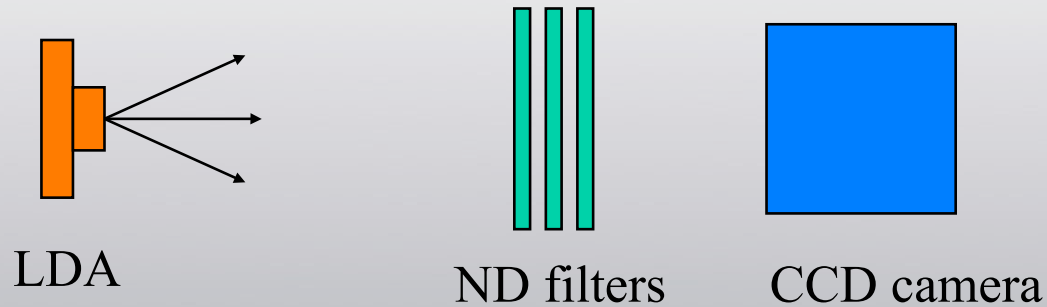


Long term power monitoring



LDA Spatially and Temporally Integrated Optical Spectra for different drive currents

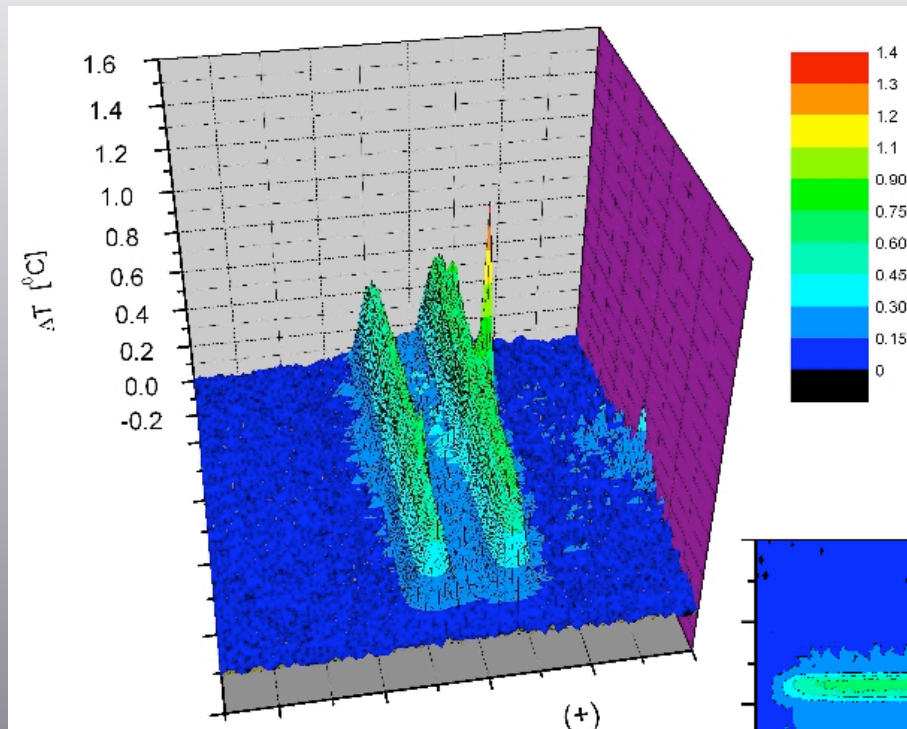
Near Field Inspection



Near-field images of the LDA under normal operation. Each bright dash is one emitter. This device has two rows of emitters and was photographed using the Si-CCD. The Brightness indicates the relative intensities of each emitter.

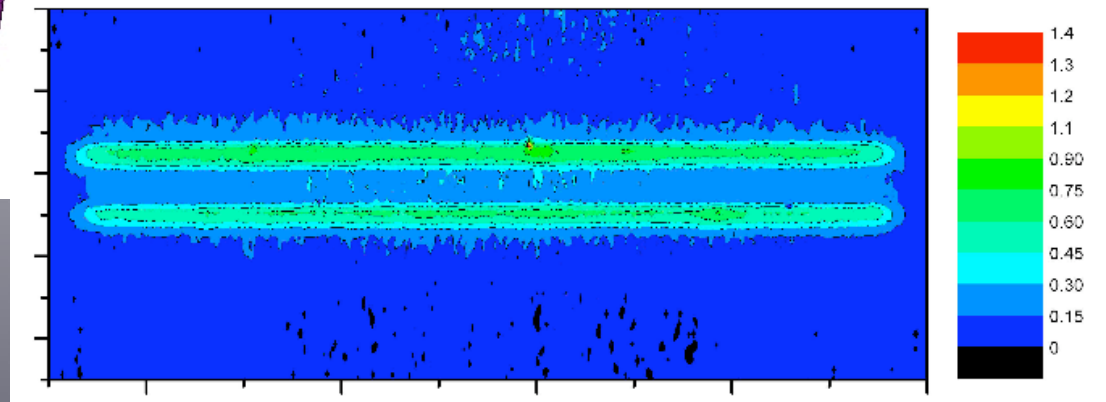
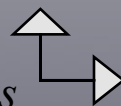
Experimental Procedure

LDA Characterization: IR Inspection

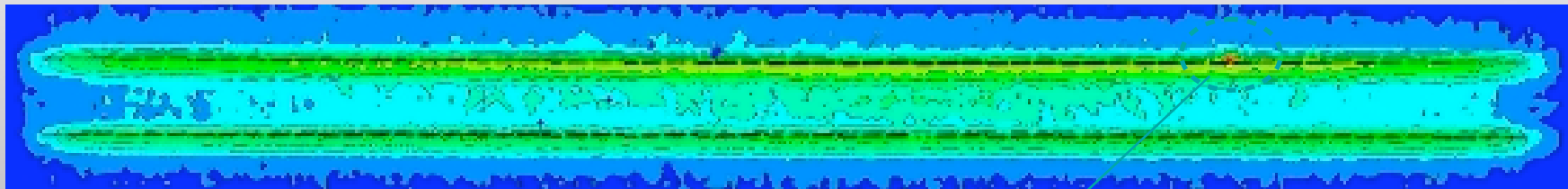


- Mid-IR camera, 3-5 μm radiation, 60 Hz frame rate, 1.7ms integ. time
- One can correct for emissivity and relative duty cycle to obtain actual surface temperature

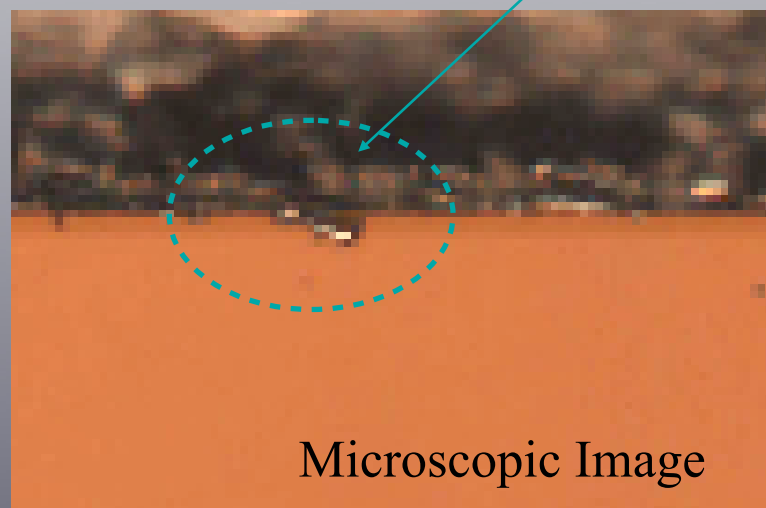
thermographic images



Correlation between Microscopic, IR & NF Images

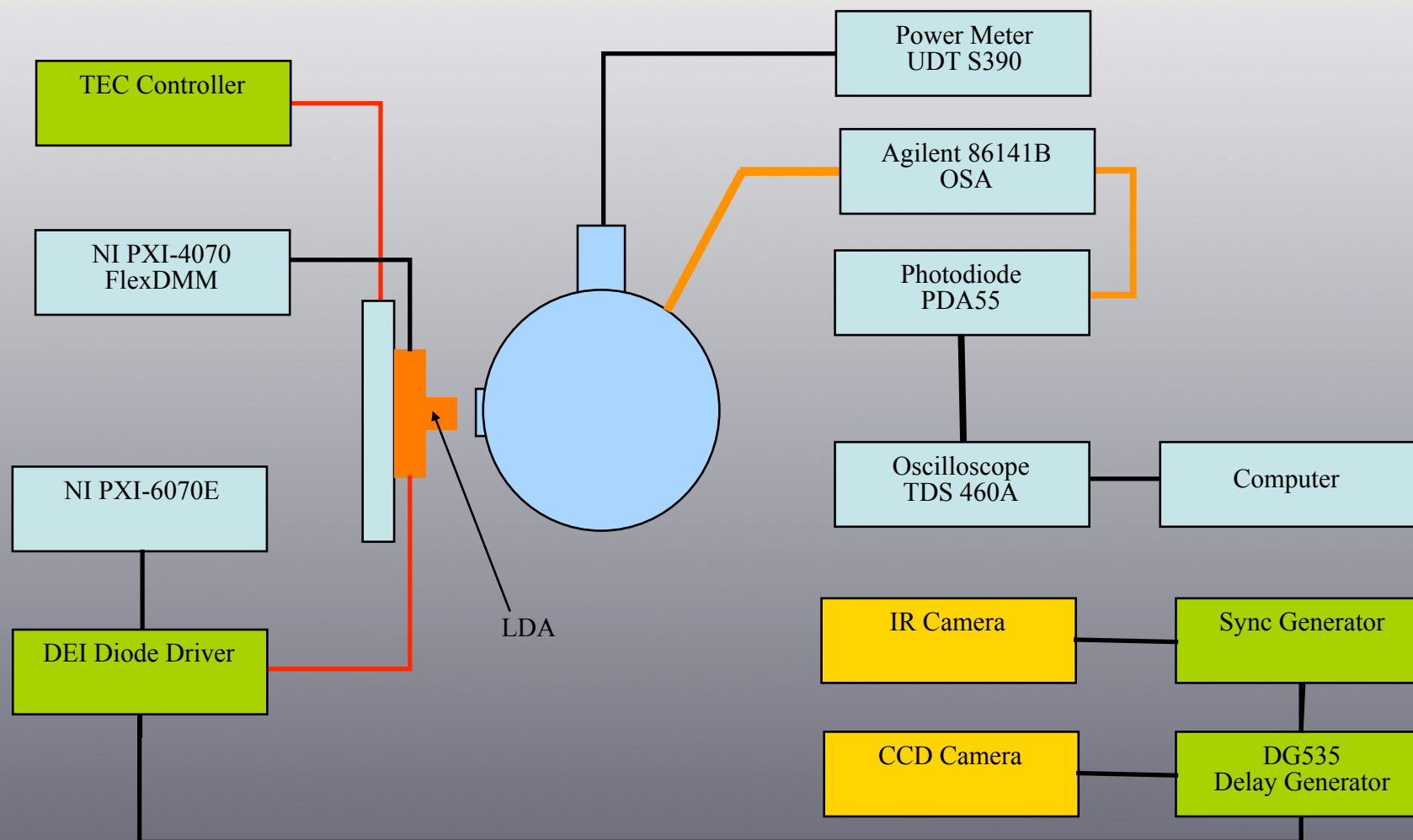


IR & NF Images (superimposed)

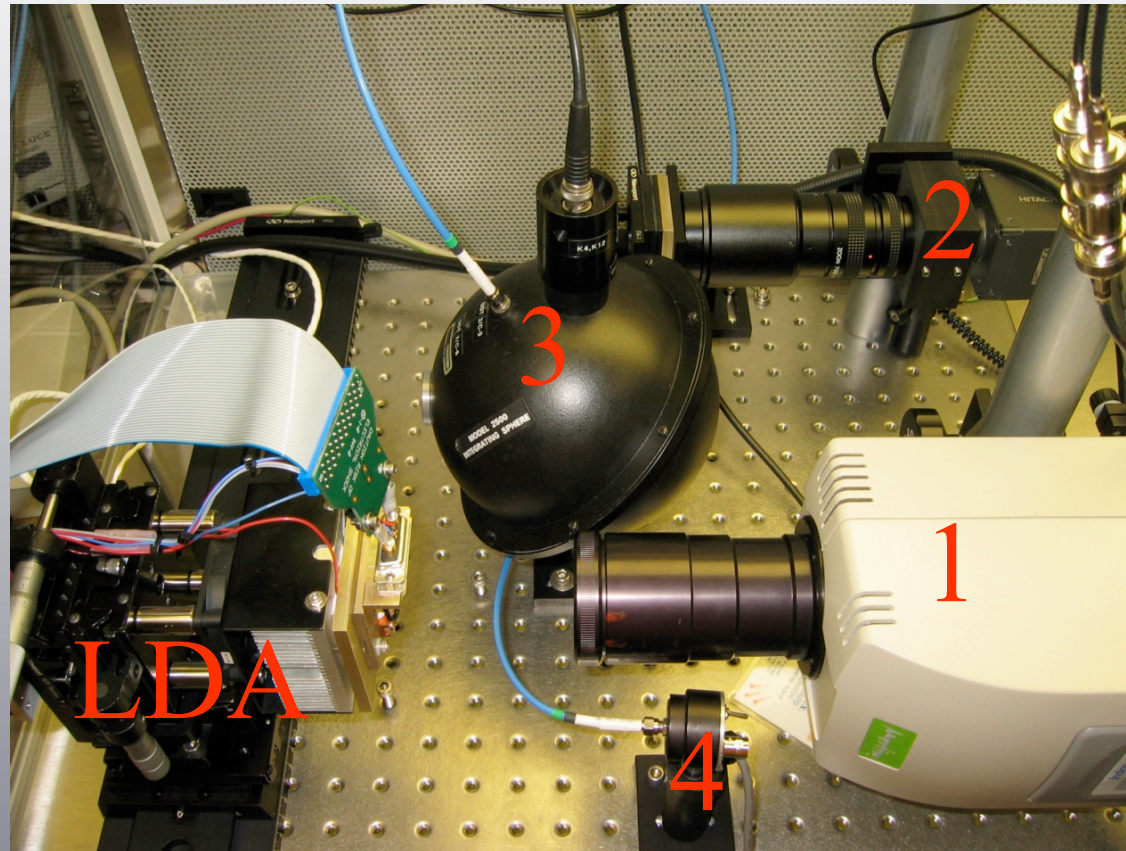


Microscopic Image

Schematic of Apparatus

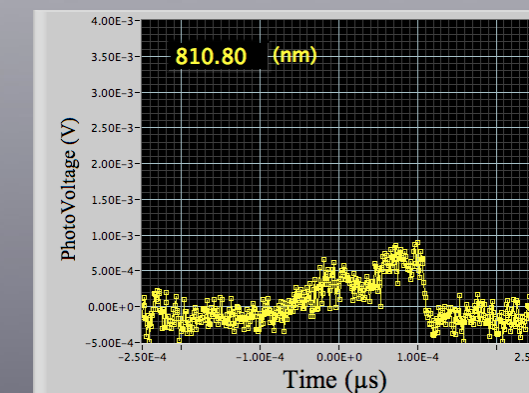
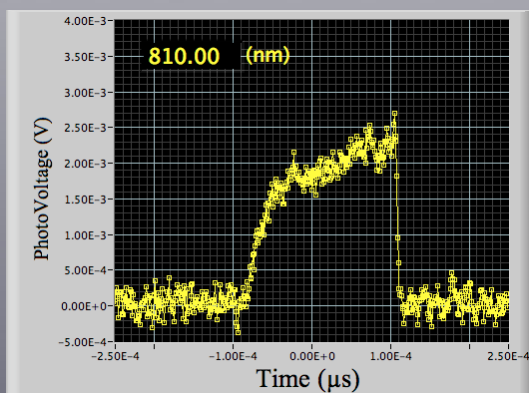
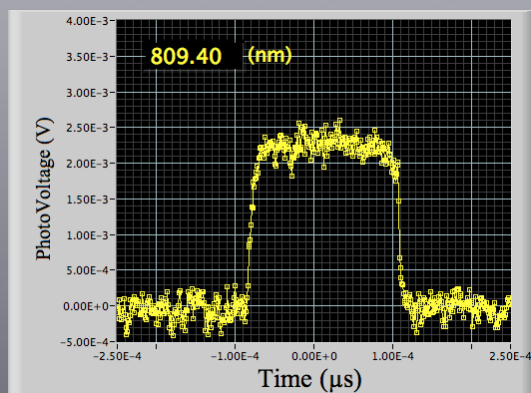
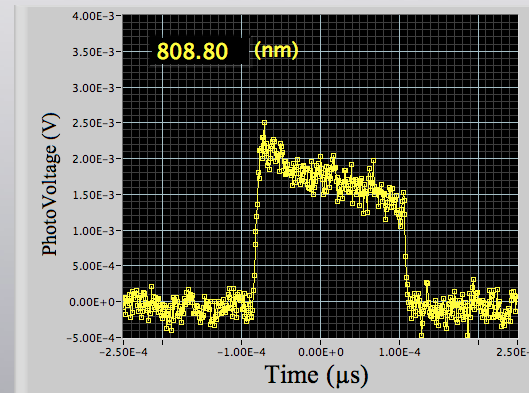
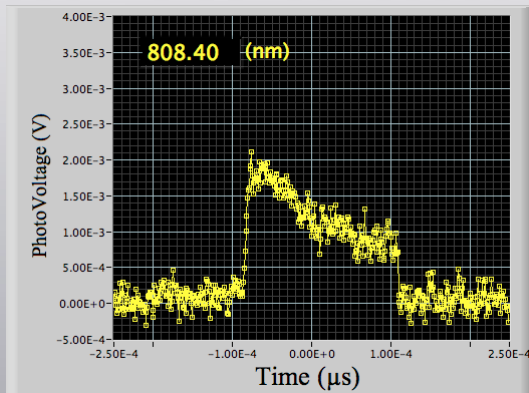
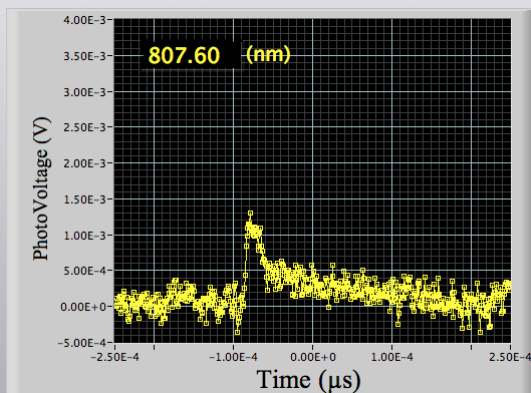


Experimental Apparatus

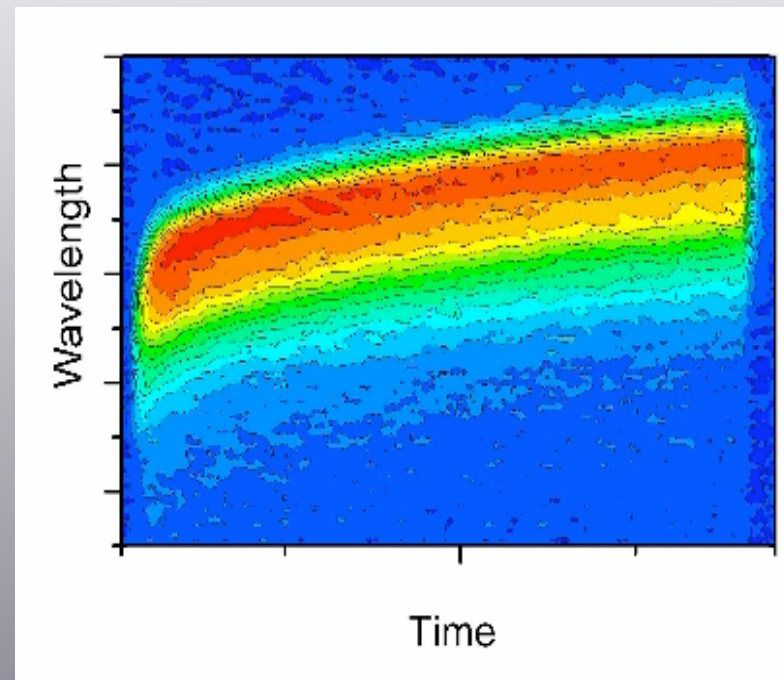
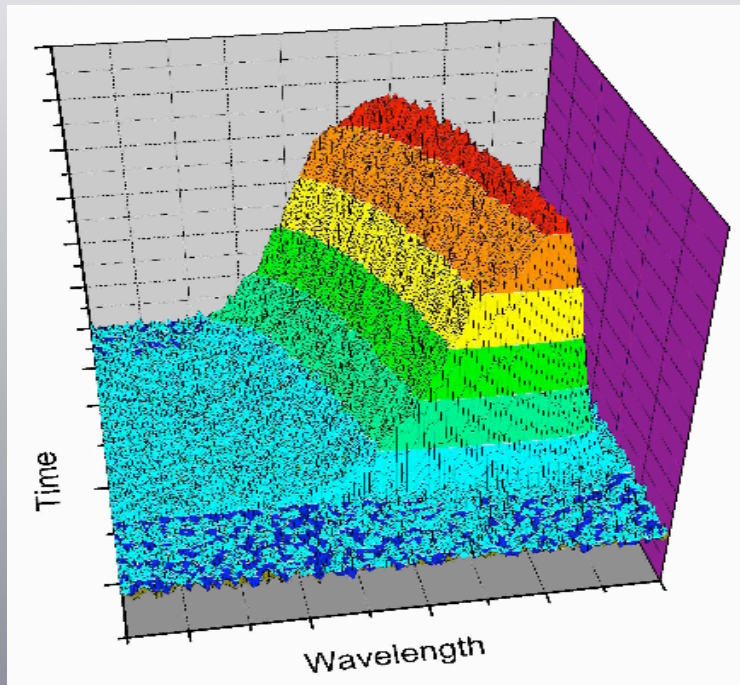


- 1 IR – Merlin MID camera
- 2 Near Field – Hitachi KP-F120 monochrome CCD camera
- 3 Optical Power – Integrating sphere model 2500 coupled with UDT S390
- 4 Spectrum & TSR – Agilent 86141B OSA coupled with integrating sphere, photodiode PDA55 [4], oscilloscope TDS 460A

Spectral Content of Output Pulse

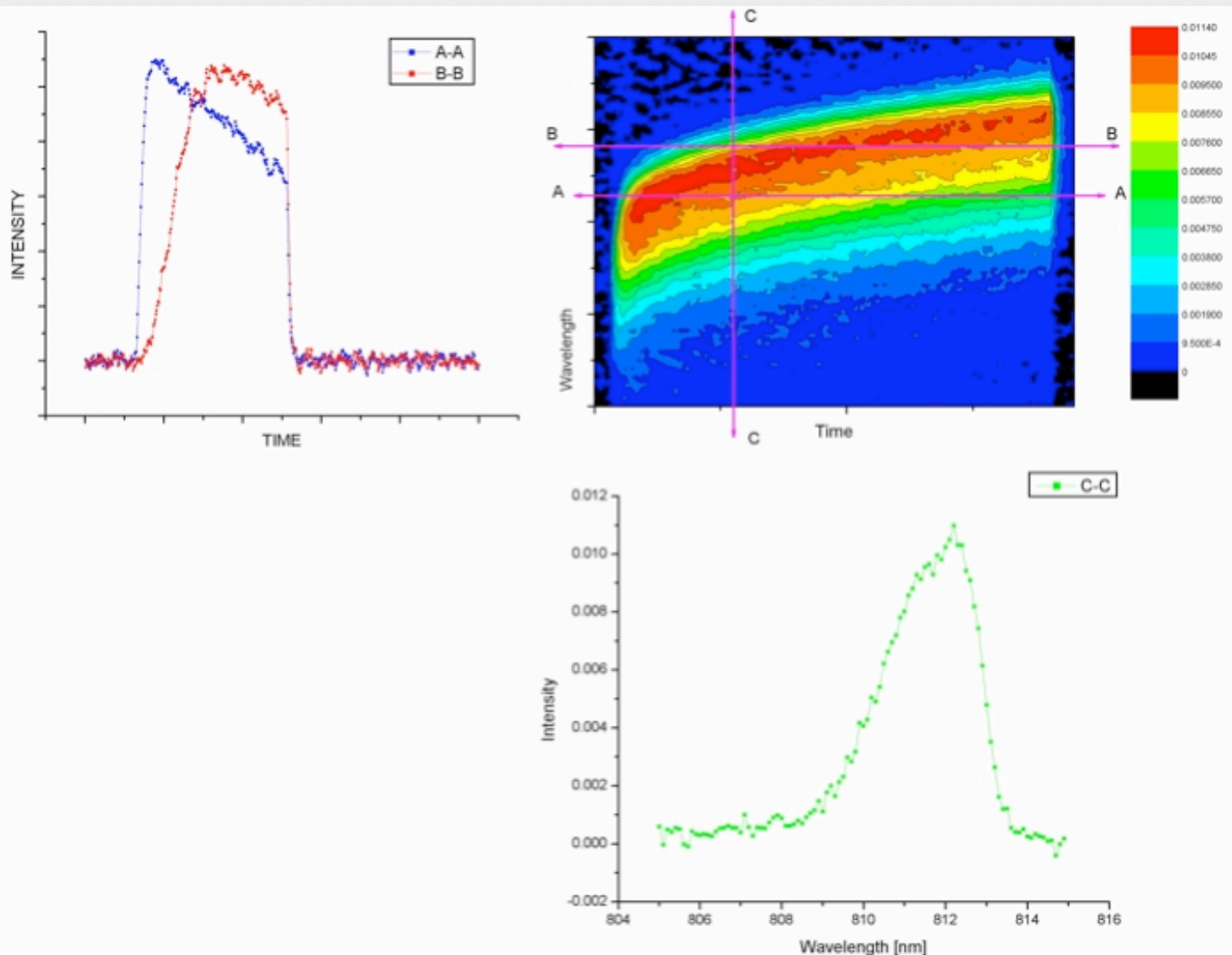


Spectral Content of Output Pulse as a function of Time

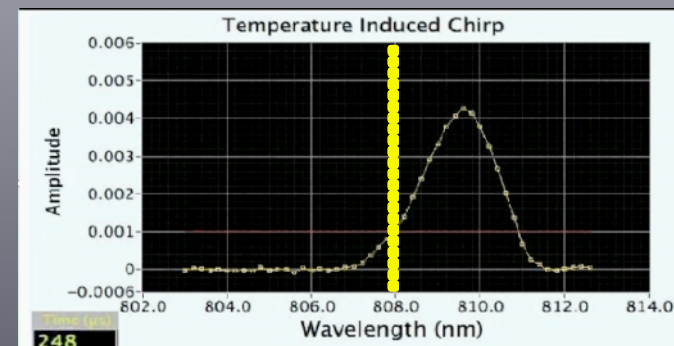
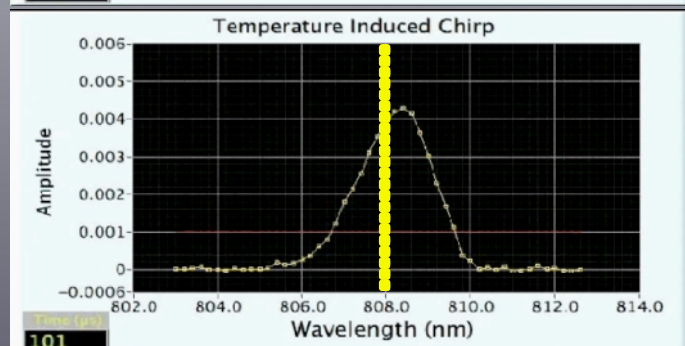
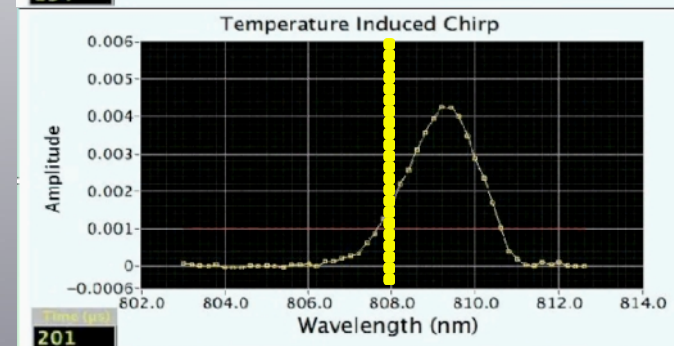
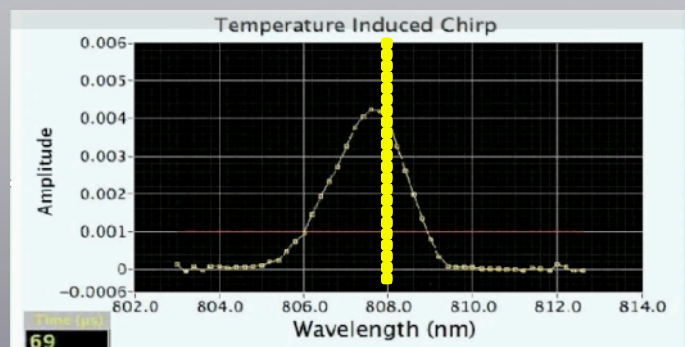
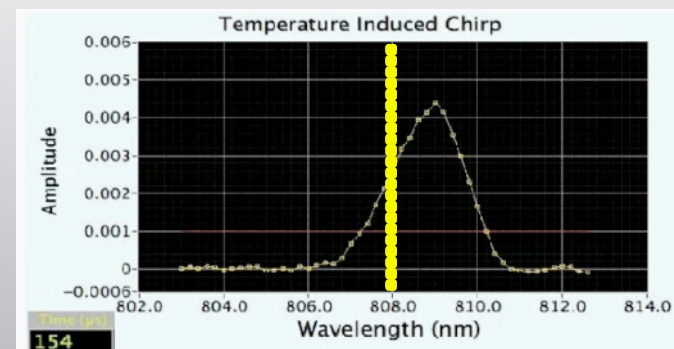
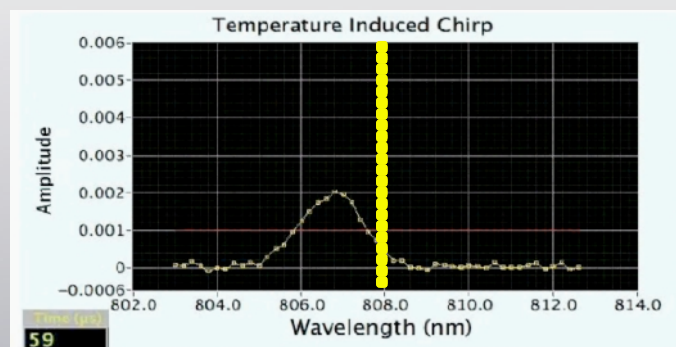


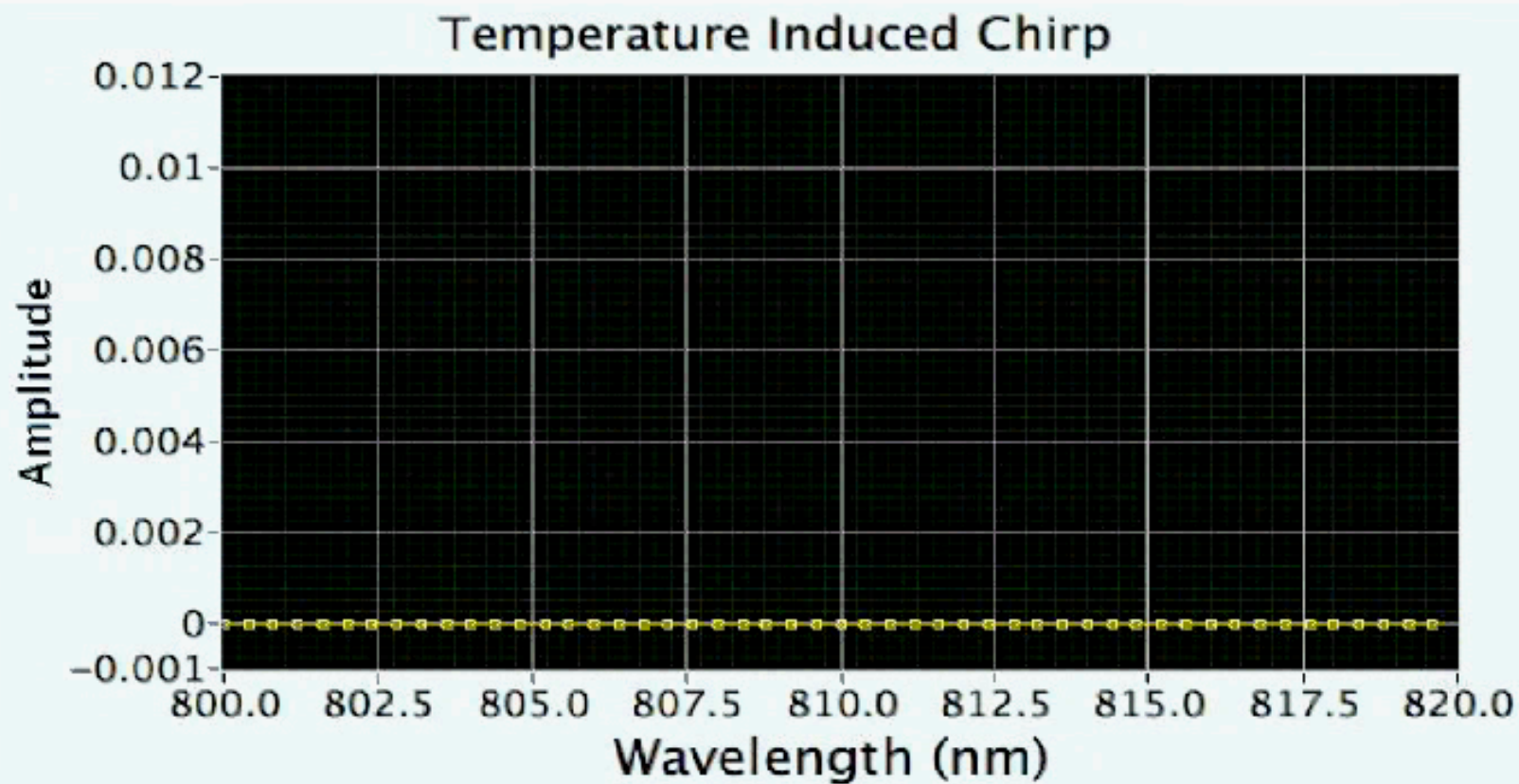
3D representation and contour plot of the spectral content of the output pulse as a function of time.
Optical Chirp

TSR Chirp Pulse Output

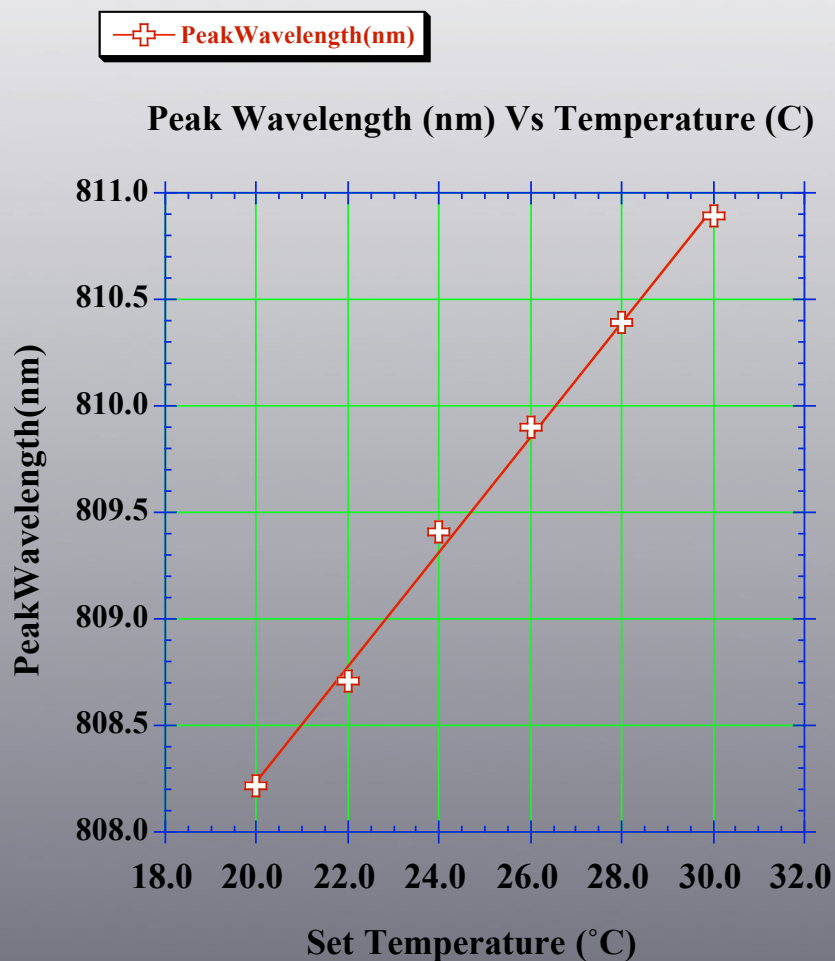


Temporally and Spectrally Resolved (TSR) Optical Power





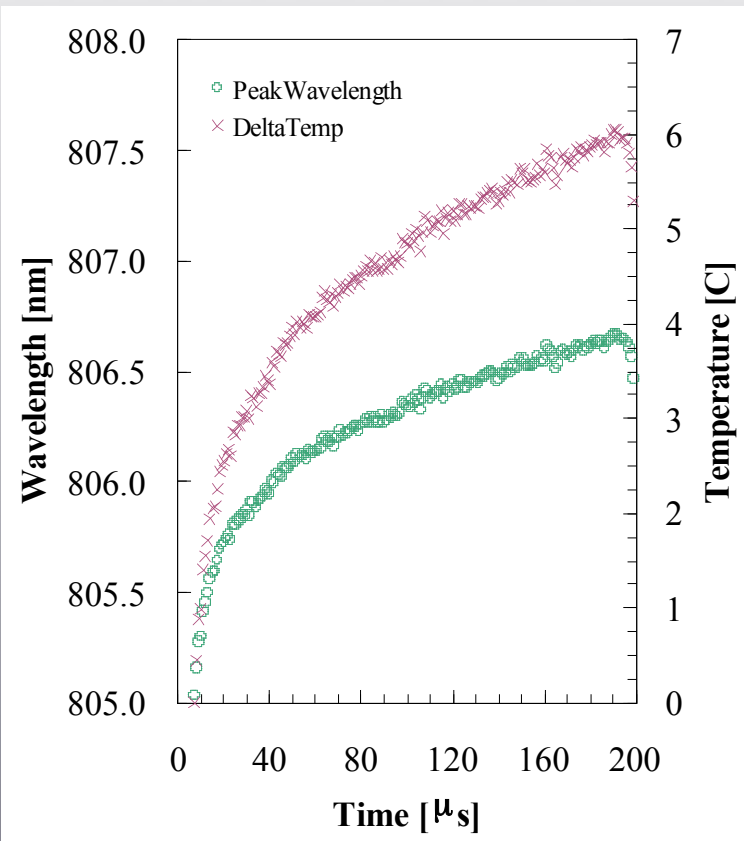
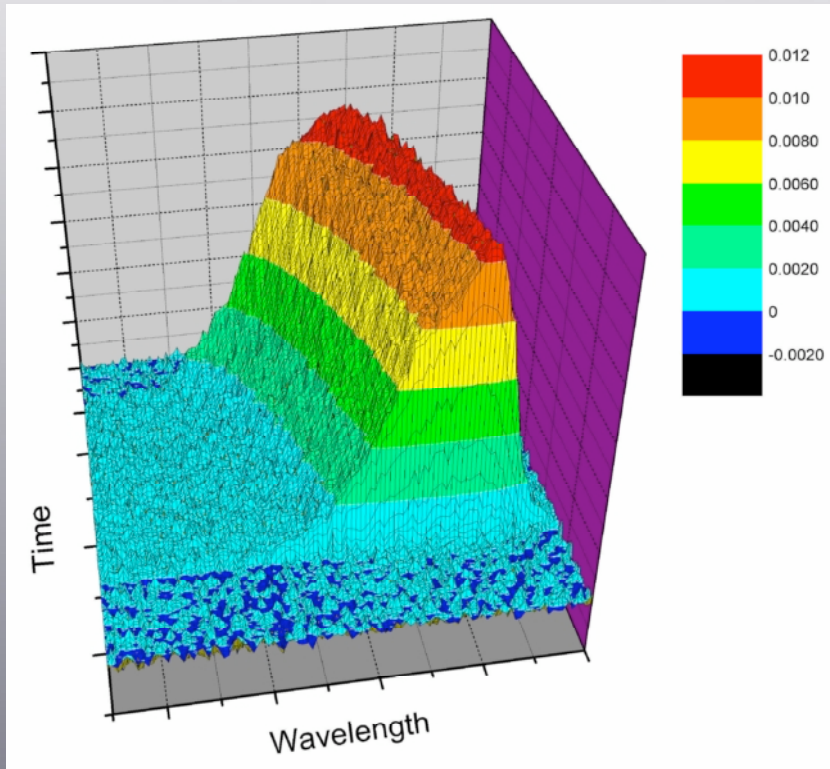
Obtain Device Temperature form the Peak Wavelength.



(~0.27nm /C°)

Peak wavelength as a function of temperature set point

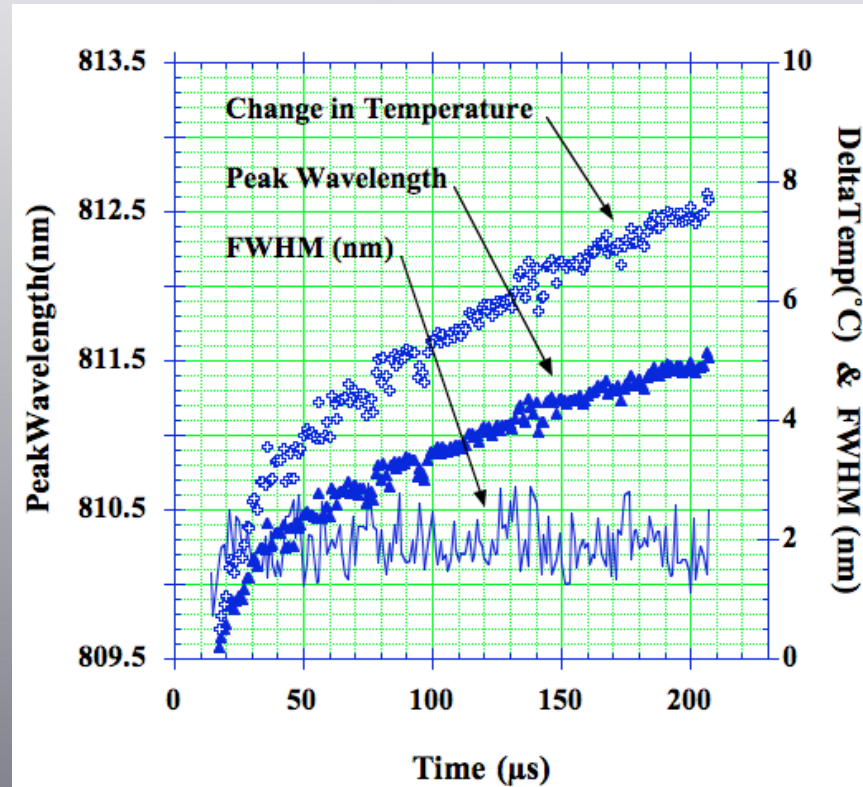
TSR Measurements*



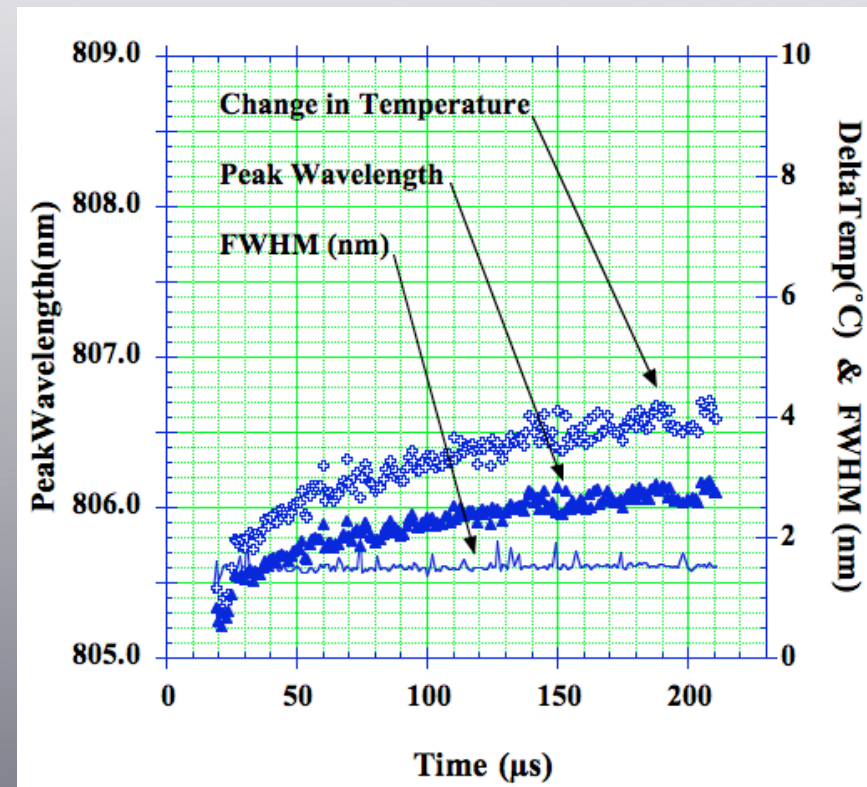
*A. Vasilyev, G. R. Allan, J. Schafer, M. A. Stephen and S. Young, "Optical & Thermal Analyses of High-Power Laser Diode Arrays", *Technical Digest, SSDLTR2004*, p.38

Comparison between two Different Devices

Device I

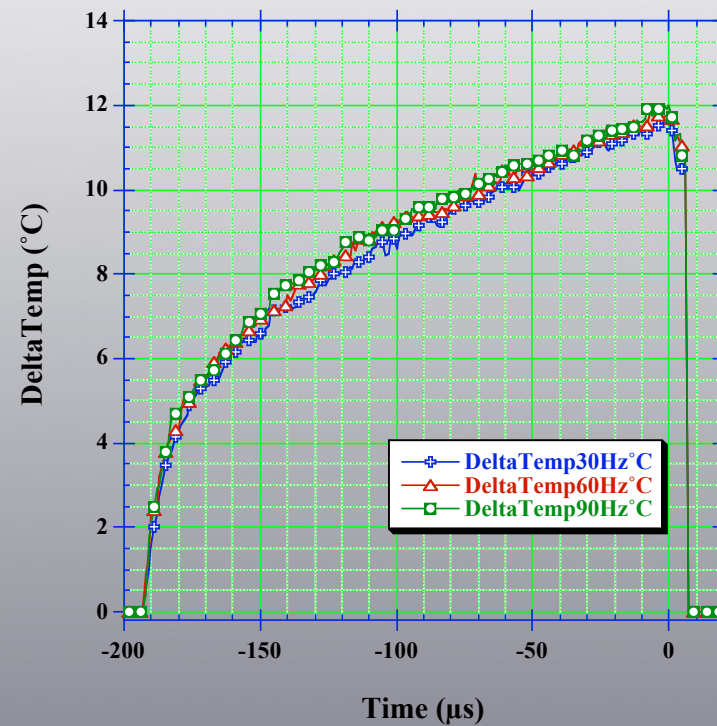


Device II



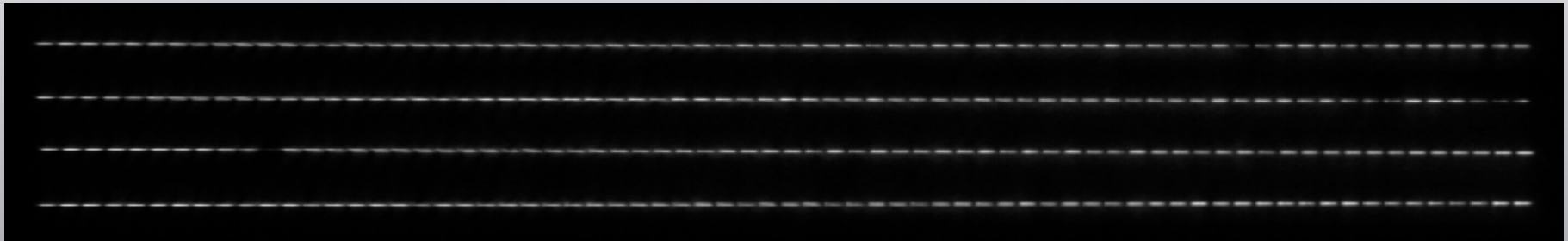
Set temperature 25 C°, again 200μs current pulse of 70 A peak.

Change in Diode Temperature as fn of Rep-Rate



Only a slight increase in temperature on increasing the repetition rate from 30 to 60 to 90Hz. Set temp = 25C°, current pulses 200μs 100A pk

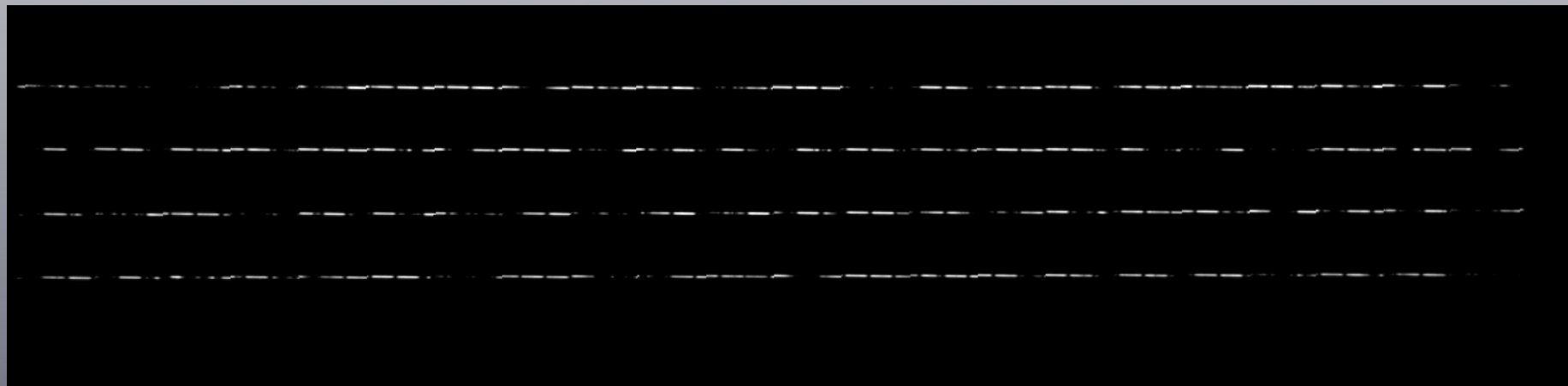
Near-field Image of a “Good” Laser Diode Array



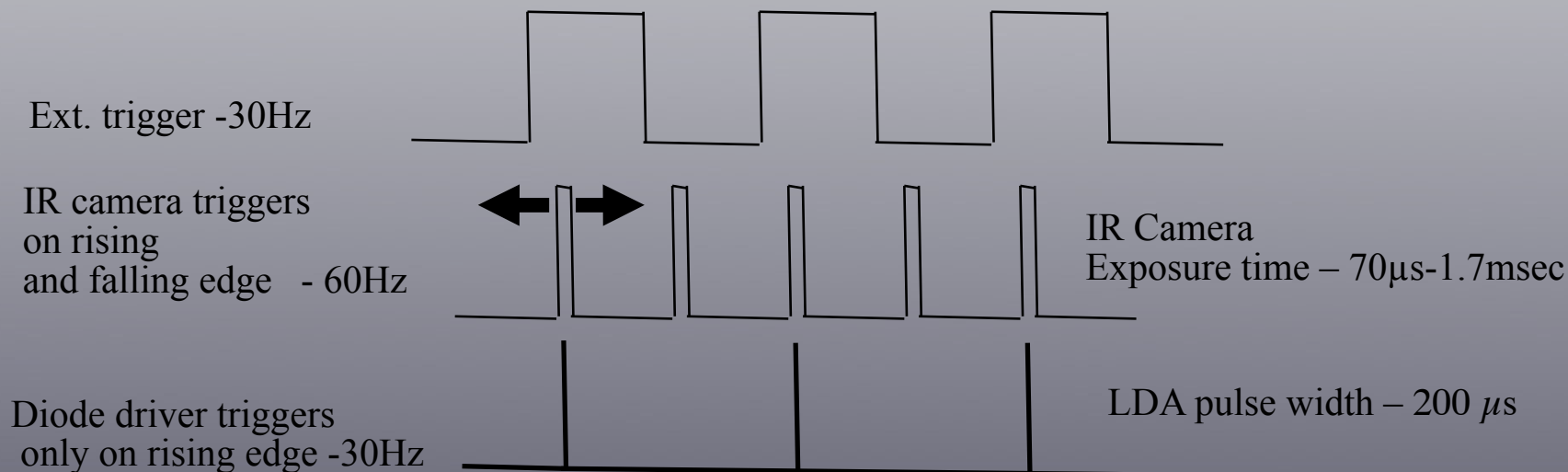
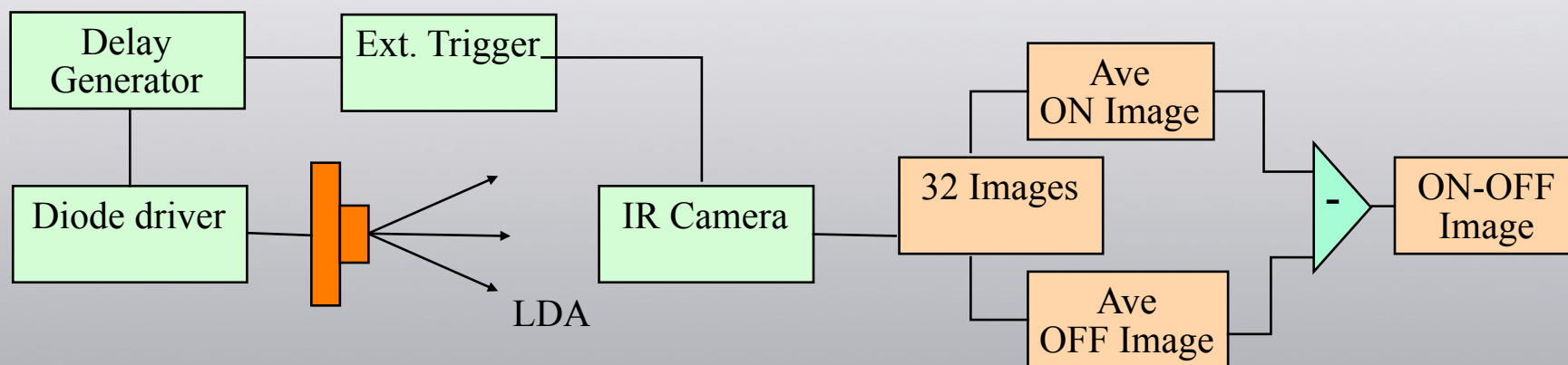
Near-field image of the LDA under normal operation. Each bright dash is one emitter. This device has four rows of emitters. There are occasional missing emitters. Captured with the Si-CCD and shows the nominally 808 nm light.

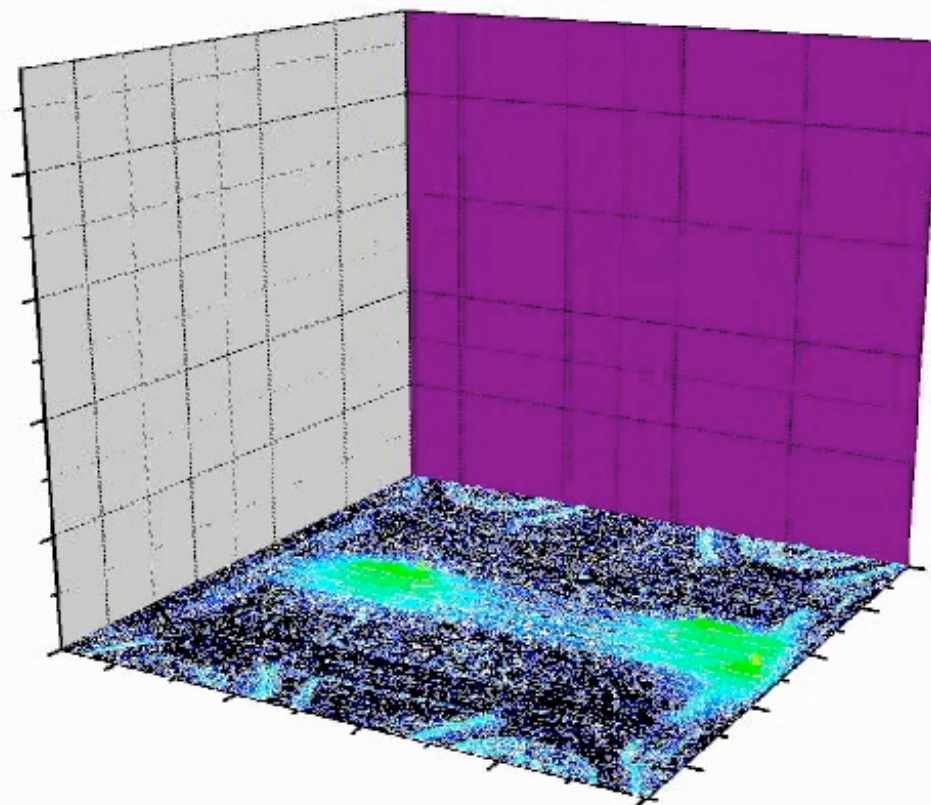


Time resolved thermographic sequence of the LDA under normal operation. This device has four rows of emitters and a few anomalous hot spots.



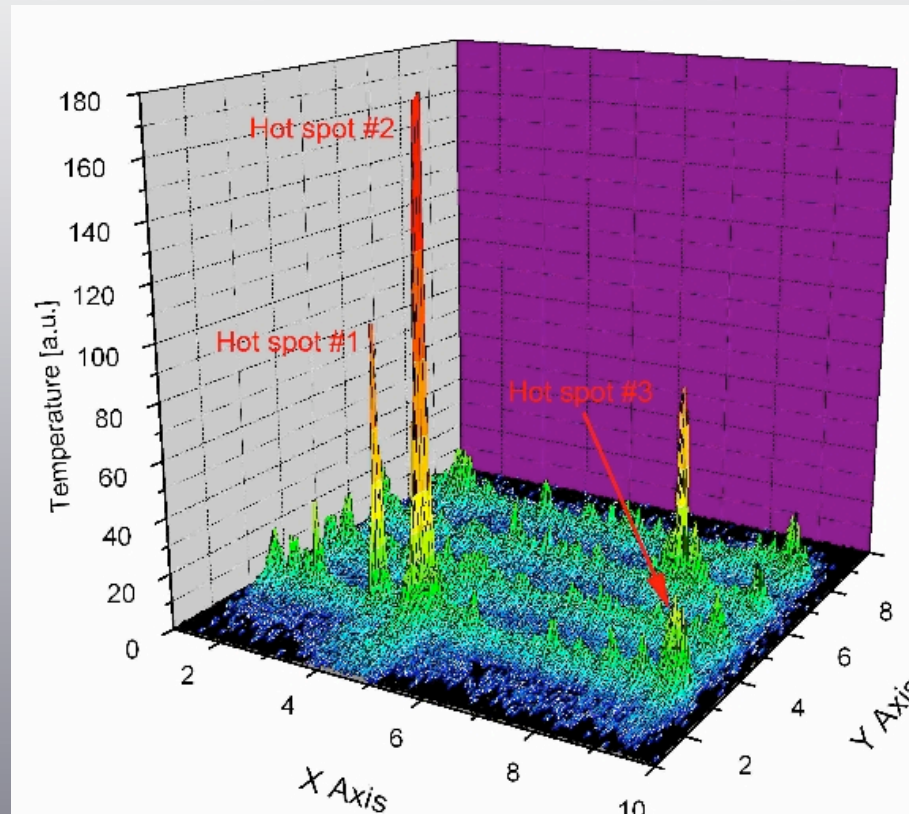
Near-field "still" image of the LDA under normal operation. Each bright dash is one emitter. This device has four rows of emitters.





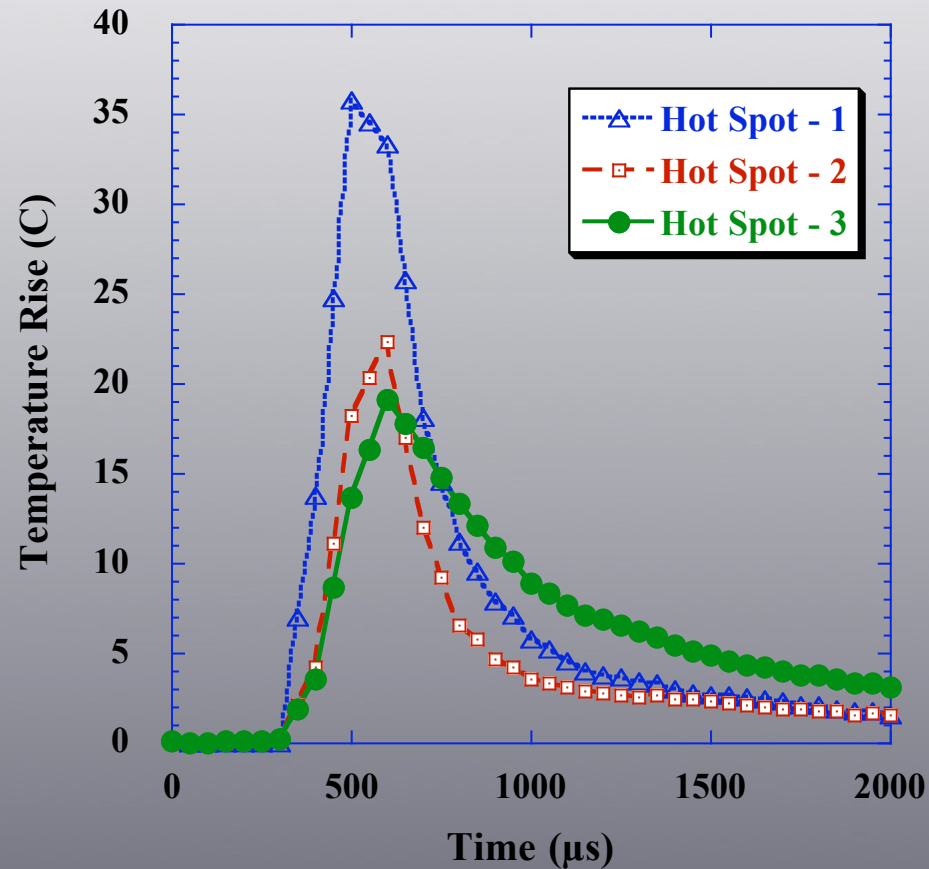
LDA Characterization

Temporally Resolved IR Measurements



Time resolved image of the front facet temperature approximately 180 μ s after turn-on of the current pulse. Three anomalous temperature regions are identified, Hotspots 1, 2 & 3.

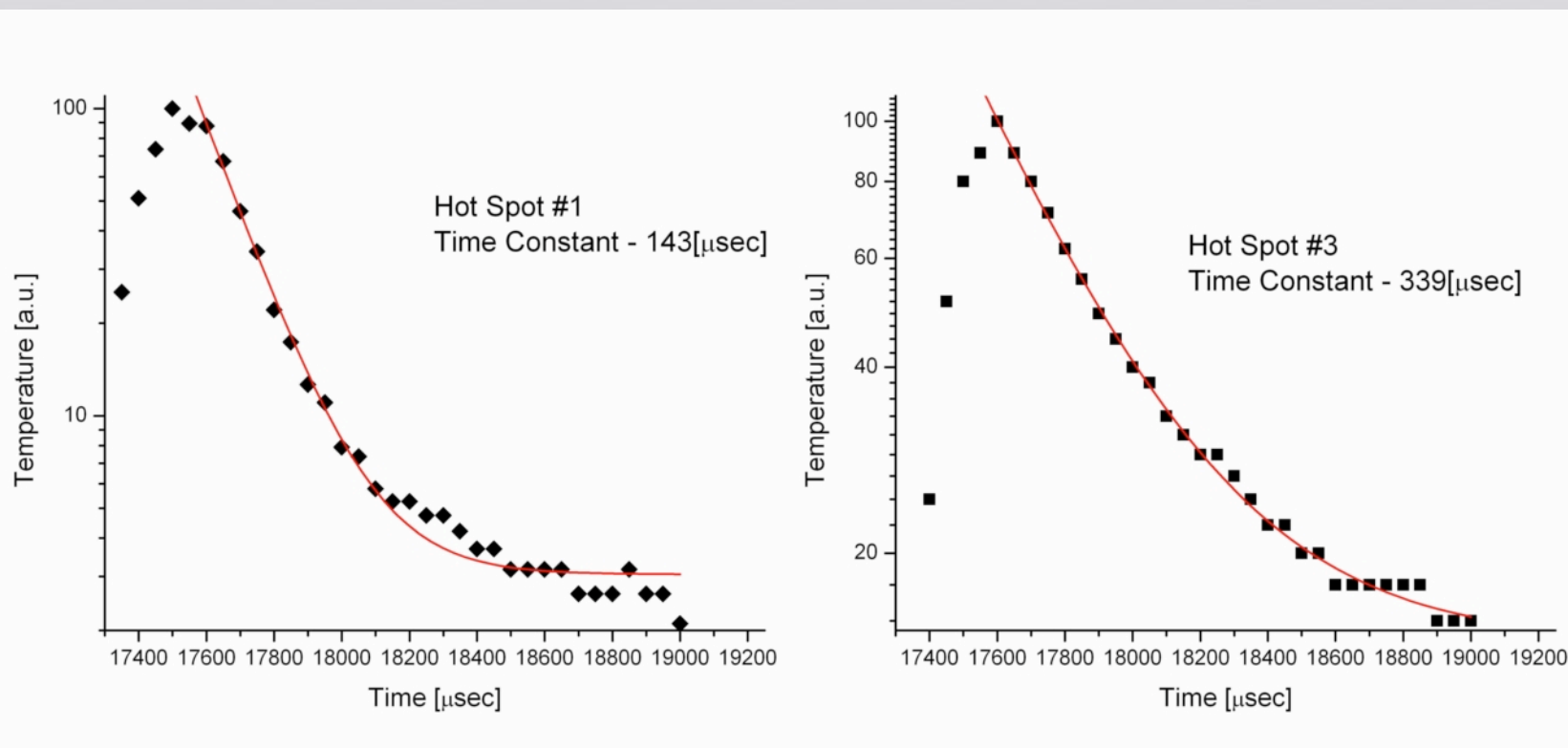
Uncorrected Temperature Rise for the Three Identified hot spots.



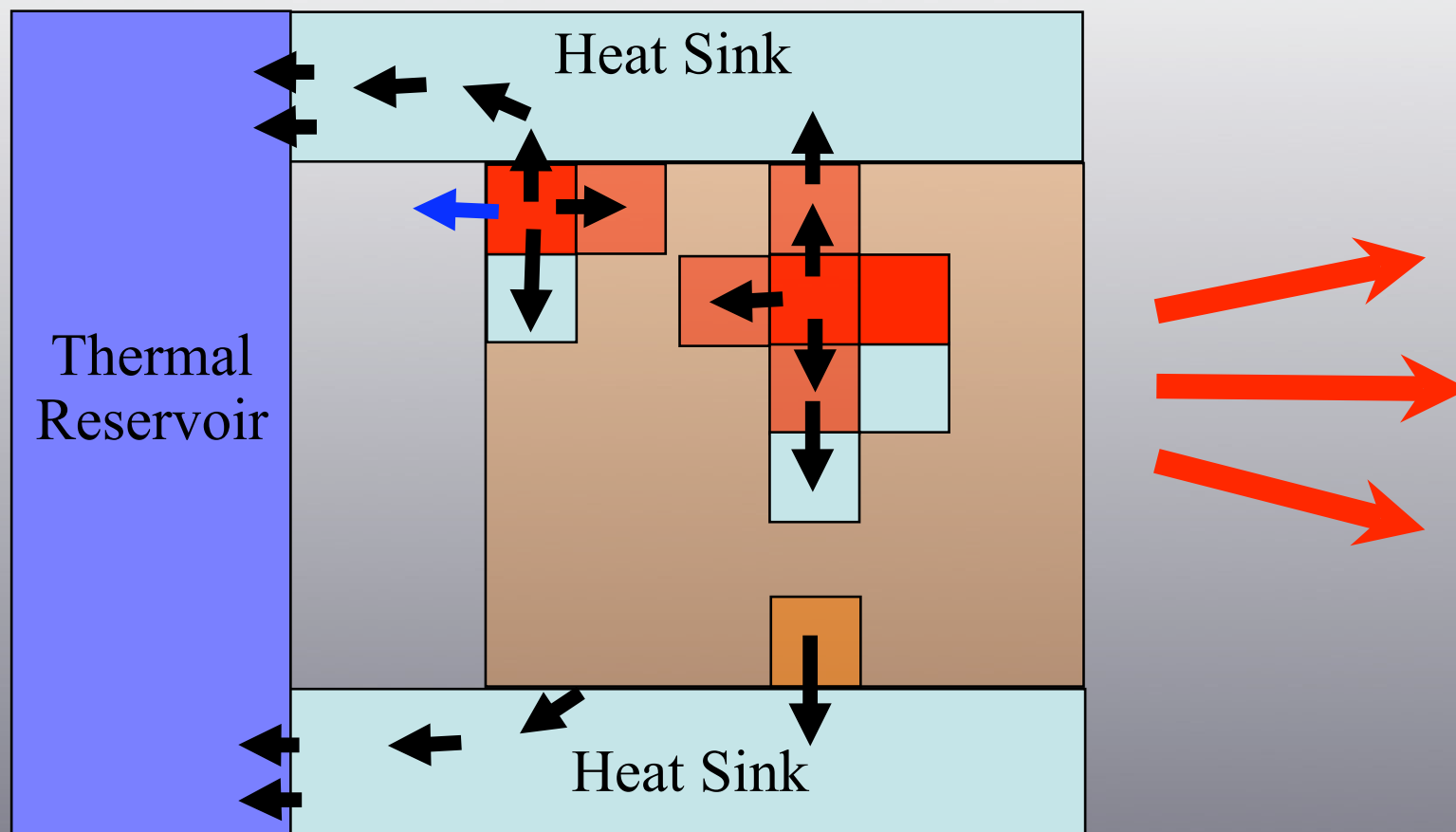
Leading edge is an indicator of the depth of the hot spot.

LDA Characterization

Temporal Resolved IR Measurements



Heat (*Energy*) Flow & the Delta Temperature matrix $\{DT_{j,k}\}$



Local temperature gradients are calculated. Thermal Energy Flow
 (time step, conductivity tensor $k_{i,j,k}$ Specific heat C , Elemental Volume,
 Mass, X-sectional Area)

The Algorithm

Start $\{T_{j,k}\}_{t=0}$

Conduction:

Calculate Thermal Gradients (adjacent elements).

Calculate energy flow in time step dt .

$$DT_{j,k} = [T_{j,k} - T_{j,(k+1)}] \cdot k \cdot a_{yz} \cdot dy / (pVC).$$

For the 3D model there are six calculations

Where “a” is the cross-sectional area between elements, p density, V volume and C specific heat.

Radiative Heat Loss

Calculate radiative heat loss from the surface:

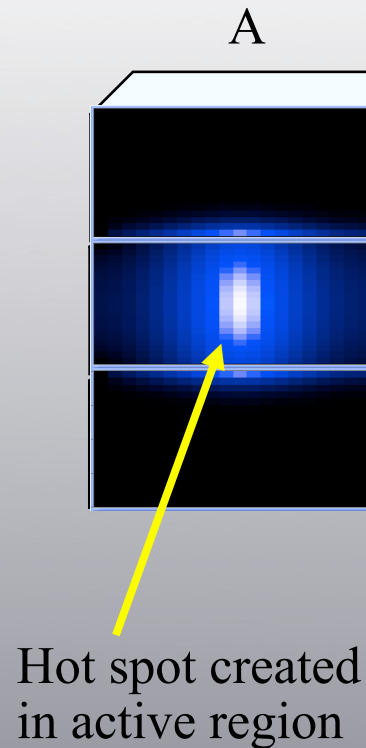
$$DT_{j=0,k} = (sT_{Bkgrnd}^4 - sT_{0,k}^4) \cdot E \cdot m \cdot dy \cdot dz / (rVC)$$

The net energy flow either cools or heats the element. $\{DT_{j,k}\}$

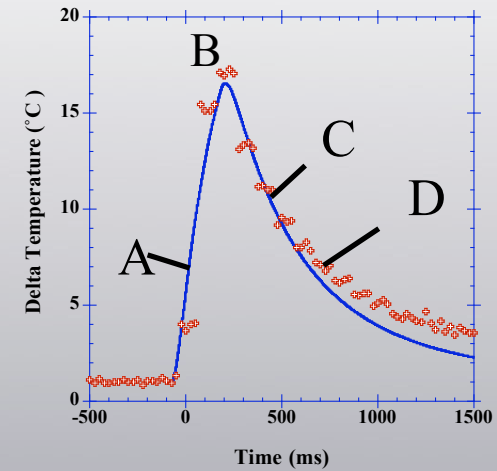
End $\{T_{j,k}\}_{t=dt} = \{T_{j,k}\}_{t=0} + \{DT_{j,k}\}$

Time step dt must be small: energy flow only perturbs thermal gradient.

Thermal Model & Fit to Data



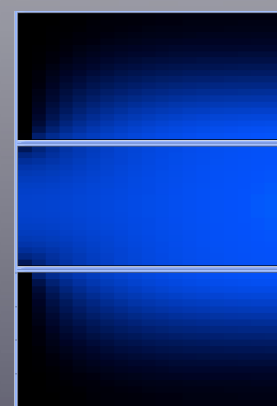
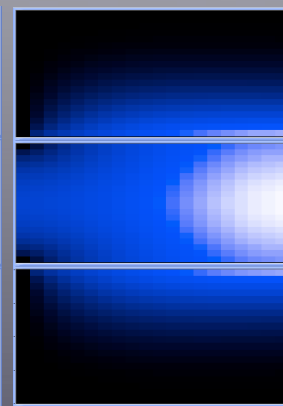
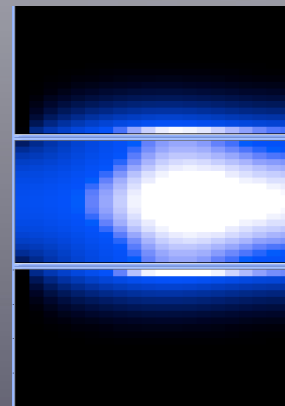
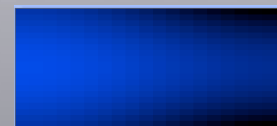
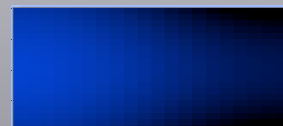
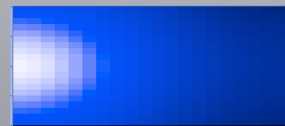
Output Face



B

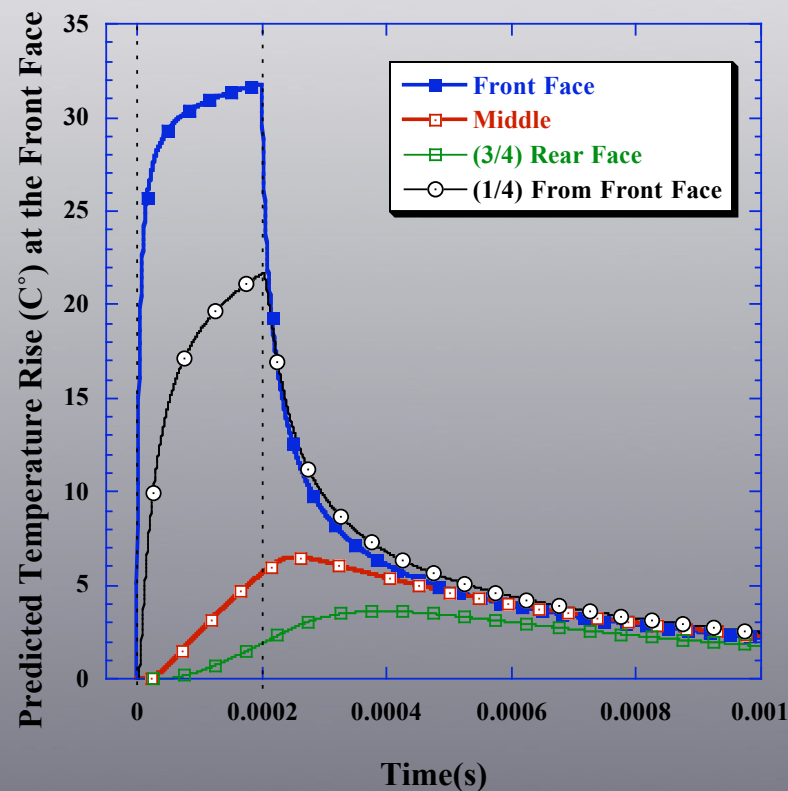
C

D



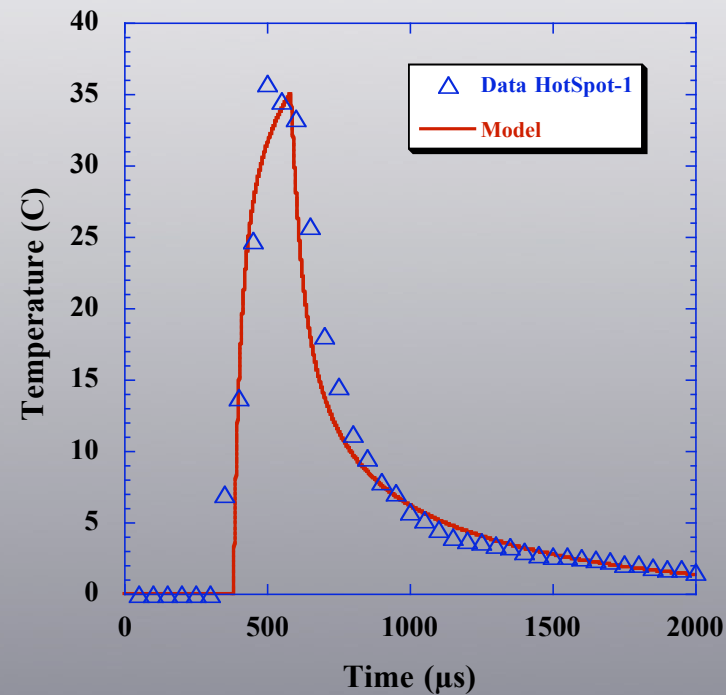
The colors within each time slot represents the temperature
White is hotter than blue, black is cold.

Predicted Hotspot Behavior as Monitored at the Output Face



The code was run for a hot spot in four different positions within the LDA.

Numerical fit to the data



Preliminary analyses indicates that this hot spot is subsurface about one quarter of the way into the LDA.



Conclusions

Time-resolved optical and thermal analyses of laser diode arrays reveals temperature induced chirp and the presence of anomalous hot spots.

TSR monitoring of the spectral chirp reveals the current induced temperature rise in the active region of the device

Time resolved thermography

Hot spot location.

Fit temporal hot-spot data with thermal model to reveal approximate location of hot spot.

Further Work.

Improve camera's temporal resolution

Refine model to study the different decay rates.